

SUSTAINED CARRIER OPERATIONS: SLEEP LOSS, PERFORMANCE, AND FATIGUE COUNTERMEASURES

David F. Neri, LCDR, MSC, USN¹

David F. Dinges, Ph.D.²

Mark R. Rosekind, Ph.D.¹

¹**Fatigue Countermeasures Program
Flight Management and Human Factors Division
NASA Ames Research Center
Mail Stop 262-4
Moffett Field, CA 94035-1000**

²**Unit for Experimental Psychiatry
University of Pennsylvania School of Medicine
1013 Blockley Hall
423 Guardian Drive
Philadelphia, PA 19104-6021**

June, 1997

Foreword

This document has been developed in response to inquiries from USS NIMITZ and COMNAVAIRPAC regarding the human performance effects of a planned 96-hr (4-day) SURGEOP. This type of operation is likely to provide only limited sleep opportunities for many individuals and perhaps no scheduled sleep opportunities for others. In providing information on what to expect in this situation, a key consideration is that some sleep versus no sleep at all over a period of several days can be very different in their effects on sleepiness, performance, and mood. During a period of total sleep loss, performance depends on many factors such as prior sleep/wake history, duration of sleep deprivation, time of day, nature of the work tasks, environmental variables, and social factors. However, there are even more factors to consider in the partial sleep situation such as the number of sleep episodes, their timing, and their length. Partly because of these differences, the data from laboratory and field studies are more abundant regarding the effects of total sleep loss than the effects of partial or restricted sleep. As a result, it is possible to provide more concrete information about total, rather than partial sleep deprivation. In the SURGEOP scenario there is the added difficulty of determining in advance the crew's sleep/wake schedules. These schedules are sure to differ greatly between groups, vary from day to day, and be largely unpredictable. For these reasons, this document will address primarily the myriad effects of *total* sleep deprivation, drawing from the latest scientific information on sleep, fatigue, and human performance. While this information is based primarily on laboratory sleep deprivation studies, where subjects are pushed to perform, many of the same outcomes can be expected in a wide range of operational environments. The approach taken in this document is to provide information on expected outcomes with the understanding that leaders can then tailor an approach to their specific environment, tasking, and crew. To the extent that sleep and/or nap opportunities are made available during the SURGEOP, the types of problems encountered are likely to be similar while the magnitude of the degradation described would be less severe.

The paper is organized into three main sections: (1) background scientific information on sleep and circadian rhythms, (2) responses to operational questions on the effects of sleep loss, and (3) fatigue countermeasures. These sections are followed by appendices that (a) summarize countermeasure recommendations for the surge period, (b) provide fatigue survey guidelines, and (c) list suggested additional sources for more detailed scientific information.

Table of Contents

Foreword.....	2
1. Background Scientific Information.....	5
Sleep	5
Circadian rhythms.....	5
2. Responses To Operational Questions.....	6
How long can the crew be expected to go without sleep before significant impairment?	6
What is the range of individual differences in response to total sleep loss?.....	7
What are the types of problems to expect with extended sleep deprivation?.....	8
<u>Sleepiness</u>	<u>8</u>
<u>Physiological and cognitive changes.....</u>	<u>9</u>
<u>Behavioral changes.....</u>	<u>9</u>
<u>Mood changes.....</u>	<u>10</u>
Could the days of reduced sleep leading up to the SURGEOP have a significant effect on sleepiness and performance?.....	11
Can individuals be relied upon to determine when they are most sleepy?.....	11
3. Countermeasures	12
What countermeasures can be used to improve the situation during a surge operation?.....	12
<u>Caffeine.....</u>	<u>12</u>
<u>Naps</u>	<u>13</u>
<u>Social interaction</u>	<u>14</u>
<u>Physical activity.....</u>	<u>14</u>
<u>Organizational factors.....</u>	<u>14</u>
<u>Diet</u>	<u>14</u>
Would stimulants be helpful?	15
<u>Amphetamines</u>	<u>15</u>

Should sleep be possible, how might work schedules be arranged to minimize the impact of changing shifts and reduced sleep opportunities?	16
What kinds of information can be gathered with minimal impact to determine the effects of this SURGEOP and serve as a comparison for future exercises?.....	17
Are there any criteria for readily determining whether a SURGEOP was conducted safely?	18
APPENDIX A: COUNTERMEASURE SUMMARY	19
APPENDIX B: SURVEY GUIDELINES	20
APPENDIX C: SELECTED ADDITIONAL SOURCES.....	21

1. Background Scientific Information

Two physiological factors that are known to have a significant effect on human performance and alertness are sleep and circadian rhythms. Some basic information on these factors is provided as a foundation for the subsequent discussion.

Sleep

Sleep is a vital physiological function, as critical for human survival as food, water, and oxygen, and as difficult to deprive as these basic physiological needs. Optimal sleep, both quantity and quality, is necessary for maximal performance and alertness. Reduced or degraded sleep can significantly decrease or impair performance and alertness. Sleep loss can degrade potentially any, and every, aspect of human performance, including memory, vigilance, decision-making, mood, and reaction time. Sleep loss can occur acutely and accumulate over time. Current scientific data have demonstrated that sleep of 2 hr less than an individual's required amount, is sufficient to significantly decrease subsequent performance and alertness. Therefore, an 8-hr sleeper who obtains only 6 hr sleep on one night can show a significant effect due to this acute sleep loss. Over time, sleep loss can build into a cumulative sleep debt. Obtaining one hour less sleep than is typically required over 7 nights would result in a cumulative sleep debt of 7 hr, equivalent to about one night of sleep lost over a week. Recovery from sleep loss is accomplished through an increase in deep sleep and not through a one-hour for one-hour payback. Studies have demonstrated that the average adult human requires 8-8.25 hr of sleep for optimal performance and alertness. There is a range of individual sleep requirements around this amount (about 6-10 hr). Therefore, it is important to provide adequate sleep opportunities for an optimal amount of acute sleep, to minimize a cumulative sleep debt, and provide adequate recovery from a sleep loss situation.

Circadian rhythms

The circadian clock, located in the suprachiasmatic nucleus of the hypothalamus, regulates daily variations in numerous physiological processes such as sleep/wakefulness, temperature, and hormone release, as well as cognitive performance. A daily trough in body temperature occurs about 1.5-2 hr before the usual wake time. This is close to the time of a daily trough in alertness and cognitive performance. Thus the circadian clock is programming the body for maximal sleepiness in the early morning hours (about 0300-0500 for a person on a typical sleep/wake schedule). There is a second period of increased sleepiness that occurs in the midafternoon, regardless of whether lunch was eaten.

A human allowed to live in an environment free of time cues (i.e., no external light/dark cycle or clocks) will extend the usual 24-hr day to a longer period, closer to about 25 hr. This extension is probably due, at least in part, to the natural internal tendency of the circadian clock to run with a cycle length that is slightly longer than 24 hr. This basic physiological property of the clock explains the relative ease of staying up later (i.e., lengthening the day) and the relative difficulty

of trying to initiate sleep earlier than usual (i.e., shortening the day). Lengthening the day is called a phase delay, while shortening it is called a phase advance. Ordinarily the clock is synchronized to the 24-hr day by the daily alteration in light and darkness. Problems can arise because the circadian clock cannot adjust immediately to an abrupt change in the timing of the light/dark or sleep/wake schedule. Therefore, when humans move to a new time zone or change their shift schedule (e.g., work at night and sleep during the day), the internal circadian clock can take from days to weeks to adapt physiologically to the new schedule. Manipulation of bright light can facilitate this adaptation. Anytime there is a lack of light cues to keep the clock synchronized, it will tend to move toward its natural, longer than 24-hr rhythm.

2. Responses To Operational Questions

In order to most directly address issues relevant to SURGEOPS, the information below has been organized as answers to key operational questions. To provide a more operationally useful document, literature citations in the body of this document have been minimized, with key references listed in Appendix C.

How long can the crew be expected to go without sleep before significant impairment?

For a crew on a typical schedule with work during the day and sleep at night, the critical wake duration after which a majority can be expected to show impairment is ~44 hr (midway through the second night without sleep).

Laboratory studies reveal that about one-half to two-thirds of the population will show performance deterioration by 44 hr of wakefulness (midway through the second, consecutive, sleepless night). After 44 hr, differences among individuals can remain large but eventually everyone begins to respond in a similarly degraded way. In laboratory studies, every person who remains awake continuously for more than 44 hr shows some significant impairment. This includes highly trained and motivated professionals. After 44 hr without sleep, performance only worsens and no laboratory subject has ever *not* become more degraded. At 64 hr and more without sleep, the performance of all individuals, even the hardest and most resistant, becomes seriously degraded. If, however, some sleep is obtained during these periods, even sleep of only a few hours duration, fewer subjects will experience severe performance deficits.

What is the range of individual differences in response to total sleep loss?

There is a wide range. About a quarter to a third of the crew can be expected to show significant impairment after only 20 hr without sleep. Another quarter to third can be expected to show impairment from 20-44 hr without sleep. While the remaining third to half of the crew might be expected to perform reasonably well up to about 44 hr without sleep, all those awake for more than 44 hr will show some significant impairment. Consequently, everyone can be expected to show reduced performance on the third and fourth days of total sleep loss, especially at night and in the morning hours.

It is not yet possible to predict in advance the response of any one individual to total sleep loss. How an individual responds to sleep loss depends at least in part on (a) skill level, (b) training, and (c) biological factors. The higher the skill level and training, the more resistant the individual is likely to be to the effects of sleep deprivation on trained performance. Also, well-learned tasks are more resistant to sleep loss than novel or high-level cognitive tasks. In this regard, junior and less experienced people are likely to be at greater risk than more senior and experienced crew. In an operational environment such as an aircraft carrier, populated by highly trained people, much of the variability may come from biological differences. However, this remains to be seen.

With the above caveats in mind, a reasonable prediction from the laboratory data is that about one-quarter to one-third of the population will have substantial performance impairment after 20 hr of wakefulness. With 20-44 hr of sleep loss, there are wide individual differences. However, as sleep loss continues to accumulate, nearly all subjects show some degree of impairment. Recent laboratory data indicate that people may have biological predispositions to total sleep loss that allow them to be categorized in the following way:

Note: These estimates below assume no sleep (total sleep deprivation). While there is some evidence similar distributions occur with limited sleep (partial sleep deprivation), this is less well documented.

- About 25-33% of the population shows significant impairment after as little as 20 hr without sleep. These people will likely deny the problem but will also likely be very impaired. They may be helped by modifications to the environment, however (see below).
- About 25-33% of the population shows impairment between 20 hr and 44 hr without sleep. These people may be carried most of the way in a SURGEOP by a structured work environment and a strong support system.
- About 33-50% of the population shows limited to no impairment up to about 44 hr without sleep. However, their performance will degrade with continued wakefulness beyond 44 hr. For these people, therefore, most problems will occur in the last 24-48 hr of a 96-hr SURGEOP.

To the extent that a high degree of organizational structure is associated with high skill, training, and discipline levels, lesser numbers of crewmembers may fall into the most vulnerable categories. However, everyone, without exception, is susceptible to the deleterious effects of sleep deprivation and only further experience with SURGEOPS (and objective evaluation of these operations) can reveal the true nature of this distribution.

What are the types of problems to expect with extended sleep deprivation?

Sleepiness: *Sleepiness will be expressed in a greater probability of unintended sleep onsets in a sleep-conducive environment.*

Physiological and cognitive changes:

<i>Microsleeps</i>	<i>Fixation</i>
<i>Lapses in performance</i>	<i>Poor communication</i>
<i>Slowed reaction time</i>	<i>Impaired decision making</i>
<i>Reduced vigilance</i>	<i>Loss of situational awareness</i>
<i>Short-term memory impairment</i>	

Behavioral changes:

Slowing down (when possible) in an attempt to reduce errors
Foregoing routine maintenance in order to perform the primary task

Mood changes:

Degraded mood
Reduced motivation

These performance decrements will increase despite increasing compensatory effort on the part of motivated individuals.

While laboratory studies have investigated the effects of sleep deprivation on health, mood, and performance, there is only a significant amount of data on the nature and magnitude of performance degradation. Furthermore, many of the laboratory results are based on studies in which the sleep loss is acute (as opposed to cumulative) and the subjects are highly supported socially, rather than left alone. Obviously the operational environment can be very different, involving cumulative sleep loss and solitary work. Nevertheless, many of the findings on performance degradation are robust enough to be expected to translate to the aircraft carrier environment.

Sleepiness. People who lose sleep not only become sleepy but also have to make a substantial effort to avoid unwanted sleep onsets. It is easy to underestimate the magnitude of the drive for sleep after an extended period without any. Sensitive laboratory measures show that, after two days without sleep, subjects will fall asleep immediately (i.e., in less than 2 min) in a sleep-

conductive environment. Such an environment is more likely to be found in a combat information center than on the flight deck, and consequently, many of the people doing the planning and other “desk work” are at greater risk to fall asleep on the job than those who are more physically active. Factors that allow the emergence of underlying sleep pressure are:

Warm temperature	Reduced social stimulation & interaction
Dim lighting	Minimal physical activity
Low noise levels	Passive, monitoring-type work

However, if there is a lull in physical activity, even persons with active job demands can fall asleep quickly after 24 hr of wakefulness.

Physiological and cognitive changes. The problems resulting from sleep loss are pervasive and insidious, affecting virtually all aspects of performance. Microsleeps are more likely to occur. These are brief (several seconds or less) episodes of total perceptual disengagement from the environment. Microsleeps can occur during periods of otherwise acceptable performance. Consequently, performance tends to become more variable and uneven -- people perform well for periods of time with brief lapses, errors, and other performance failures interspersed. Lapses are failures to respond to information, or failures to respond in a timely manner. There is also a general tendency toward slower performance, resulting in longer reaction time. The tendency to experience microsleeps, lapses, and slower reaction times combine to result in reduced vigilance.

Short-term memory can become impaired. That is, newly learned information becomes difficult to store and retrieve from memory. Fixation on a particular task or component of a task can also occur, resulting in failures to perceive and process other possibly critical information. Communication often becomes reduced in amount and effectiveness. Decision-making can be impaired, with people showing a tendency to choose options that involve less effort, even though they have a known lowered probability of success. There can be a general loss of situational awareness in all environments, not just in aircraft. In general, the performance problems described above are more likely to occur on novel or higher-level cognitive tasks, while well-learned tasks are more resistant to the effects of sleep loss.

Behavioral changes.

Giving up speed for accuracy. The nature of the performance difficulty can depend on the type of task. On tasks where people can proceed at their own pace, there is a marked tendency to slow down in order to maintain accuracy. This occurs despite explicit instructions and attempts to work as quickly as possible. As an example, studies of army artillery teams operating in the field for up to four days without sleep found them continuing to fire artillery with accuracy but expending fewer rounds with each successive day. Where it is not possible to slow down because the work is paced by others or a machine, there is a tendency to commit more errors and be less accurate.

Sacrificing routine maintenance. When sleep deprived there is a general tendency to change how one allocates limited mental and physical resources. In the operational environment this tendency often can result in shedding maintenance and other routine tasks in order to perform one's primary task. This is a particular problem for those working with complex systems or systems requiring maintenance during the period of sleep deprivation. For example, studies have shown that, after long periods without sleep, soldiers continue to fire their weapons accurately, but clean and maintain them less often, thereby becoming militarily ineffective due to escalating rifle jams. As a result, despite adequate performance in the short-term, the risks of mechanical breakdowns and safety problems become increasingly great.

Mood changes.

Degraded mood. There is a general degradation of mood with sleep deprivation. While there is a tendency to dismiss this outcome, mood is undeniably important to morale and to effective crew communication and resource management. This problem may be especially important in the military where degraded moods on the part of higher-ranking personnel can make it even more difficult for subordinates to communicate with them frankly and effectively. In army field trials involving sleep loss, soldiers became militarily ineffective much sooner when field commanders had difficulty coping.

Reduced motivation. People can function physically when sleep deprived but will want to quit earlier due to feeling that they do not have the energy to continue. There is a marked reduction in motivation. The sleep loss itself tends to become the predominant theme. People change their behavior as a result. Among other things, they eat less and may need to be encouraged to obtain meals and look after their own basic needs. Nevertheless, effort increases at the same time that motivation (i.e., desire to continue) and performance both drop. One keeps trying to do a task if asked or required, even though one does not want to continue. In order to keep going, ever greater compensatory effort is expended. This effort is often accompanied by a reduced ability to control what is happening in the environment and so can lead to anger, frustration, emotional outbursts, and cutting corners to conserve energy. Army field studies involving total sleep deprivation indicate that commanders often need to resort to persuasion to keep troops performing.

Could the days of reduced sleep leading up to the SURGEOP have a significant effect on sleepiness and performance?

Restricted sleep (partial sleep deprivation) in the days prior to the 4-day SURGEOP can have a substantial negative effect on alertness and performance during the SURGEOP.

The days prior to a SURGEOP may not afford opportunities for optimum, or even usual, amounts of sleep. This can have important effects when the surge starts. Whereas results from laboratory sleep deprivation studies often are based on subjects who started the experiment without any sleep debt, crewmembers are more likely to be carrying a substantial debt. If the amount of sleep is treated as if it were a bank account, the crew will be starting a key evolution in debt or “in the red.” Depending on the severity of their sleep debt, they may begin to experience the effects of total sleep loss sooner than expected. Every effort should therefore be made to provide adequate sleep opportunities prior to the surge so that the crew will be starting without any existing debt but rather “in the black.” Fortunately, recovering from lost sleep does not require an hour-for-hour payback. That is, the loss of eight hours of sleep does not require eight additional hours to make-up. Allowing two consecutive nights of “recovery” sleep after a period of reduced sleep (and prior to the surge operation) should ensure a virtually complete return to baseline sleepiness and performance levels.

The emphasis on catching up on sleep before a critical period is based on the fact that nightly sleep reduction of as little as two hours (e.g., 6 hr sleep for an 8-hr sleeper) can have an operational impact. This magnitude of sleep reduction leads to an increase in sleep tendency (i.e., a greater likelihood of falling asleep in a sleep-conducive environment) and a decrease in cognitive performance. While these effects can be present after only one night of sleep reduction, they are usually evident by the day following the second night of restricted sleep. As the sleep debt builds with successive days of restricted sleep, alertness and performance *continue* to decrease. For example, while there can be some leveling off in sleepiness and performance over days 2-5 of a week with 5-hr of nightly sleep, by the sixth or seventh day sleepiness, fatigue, and performance all show increases once again. Thus, complete adaptation does not occur and a steady state of sleepiness is not achieved, despite this steady nightly sleep duration of 5 hr -- not an unusual amount in many operational environments.

Can individuals be relied upon to determine when they are most sleepy?

A person is not a reliable judge of his or her own level of biological sleepiness.

Careful studies using physiological measures of sleepiness have shown that people can report a high level of alertness during the day and yet still exhibit significant physiological sleepiness. (A daytime sleep latency of five minutes or less is considered evidence of severe sleepiness.) Therefore, in attempting to judge how sleepy an individual is, the worst person to ask is that

individual. It is better to rely on other signs and symptoms of fatigue that are related to the performance decrements described earlier:

nodding off	poor communication
slowed reaction time	poor decision making
reduced vigilance	apathetic
forgetful	lethargic
fixated	bad mood

3. Countermeasures

What countermeasures can be used to improve the situation during a surge operation?

Strategic use of caffeine and napping, increased social interaction and physical activity, along with close monitoring and a strong organizational structure can act to reduce the negative effects of sleep loss. Other countermeasures are available but require special intervention (e.g., stimulants).

A one-page countermeasure summary is also provided in Appendix A.

Caffeine. Caffeine is an effective stimulant but one to which many people have become less sensitive due to regular and heavy use. Shipboard environments are famous for heavy caffeine consumption. To enhance caffeine's effects in regular users, crewmembers should be encouraged to cut back significantly on caffeine (but not stop its use) for at least two days before the SURGEOP (preferably a week) and avoid caffeine until 18-20 hr into it. Certainly by two days before the start of the SURGEOP caffeine consumption should have been reduced by half. This reduction needs to include chocolate and caffeinated soft drinks as well as coffee (see table, below). There is some evidence that such a reduction can re-sensitize the individual to caffeine's stimulant effects. Caffeine should then be used *strategically*, starting in the late night/early morning hours (0100-0300) and tapered as morning approaches (0800). Caffeine takes about 30 min to have an effect (peak plasma levels occur in 30-60 min) and its stimulant effects last for about 3-4 hr (half-life is about 3-7 hr). Some caffeine may be necessary again in the mid afternoon to counter the mid afternoon dip in alertness that occurs whether or not lunch was eaten. Caffeine should not be taken during relatively alert periods nor within several hours of sleep onset, although this may not be a problem in a surge operation in which sleep onset is delayed 30+ hr. Although it is possible to initiate sleep with caffeine in one's system, sleep can be shortened and disrupted unless there has been prolonged prior waking.

(More detailed discussion on caffeine as a fatigue countermeasure in military SUSOPS can be found on the internet at www.namrl.navy.mil/clinical/twg/caffeine.htm)

Caffeine Content of Selected Beverages and Foods

Item	Amount	Caffeine (mg)	Item	Amount	Caffeine (mg)
Coffee	5 oz cup		Cola beverages	12 oz	
Drip method		90-150	Coca-Cola Classic		46
Percolated		64-124	Pepsi		38
Instant		40-108	Coke		46
Decaffeinated		2-5	RC Cola		36
Tea, loose or bags	5 oz cup		Diet Pepsi		36
5-minute brew		20-50	Diet Coke		46
Tea products			Diet RC Cola		48
Instant	5 oz cup	12-28	TAB		46
Iced tea	12 oz can	22-36	Other soft drinks	12 oz	
Chocolate products			Dr Pepper		41
Hot cocoa	6 oz	2-8	Diet Dr Pepper		41
Milk chocolate	1 oz	1-15	Mountain Dew		54
Sweet dark chocolate	1 oz	5-35	Mellow Yellow		52
Chocolate milk	8 oz	2-7	Diet Mellow Yellow		12
Chocolate-flavored syrup	2 tbsp	4	Mr Pibb		40

from Lieberman, H. R., 1992, *Caffeine*. In A. P. Smith & D. M. Jones (Eds.), *Handbook of Human Performance*, Vol. 2: *Health and Performance*, London: Academic Press, p. 52.

Naps. Crewmembers should be encouraged to obtain sleep whenever possible. Some sleep is always better than none. Rest, however, is no substitute for actual sleep. Sleep should be obtained wherever and whenever possible. A NASA study examining the effects of a 40-min rest period on the flight decks of commercial airliners showed that, during actual operations, a brief nap can significantly increase performance and alertness. The need to sleep is not a sign of weakness but a response to a basic and vital physiological need, like that for food and water. During operations a brief nap can significantly improve performance and alertness. If an individual needs to be alert and fully functional upon awakening from a nap, the duration of the nap should be limited to about 45 min or less. This will reduce the chances of awakening from deep sleep which can lead to a period of grogginess and disorientation known as “sleep inertia.” This state usually dissipates after 10-20 min, even less with physical activity. If a longer time period is available, a nap of 2 hr will likely assure that a complete sleep cycle will be obtained and awakening will not occur from deep sleep. Ideally, the sleep environment should be dark, cool, and quiet.

Nap Timing. Naps can be very effective if taken just before or during the early part of a lengthy sleep deprivation period (i.e., prophylactically). *An improvement in performance is often seen after the nap, even when the individual does not report feeling more rested.* The circadian rhythm of alertness dictates that the times when crewmembers are likely to feel most sleepy are about 0200-0800 and 1400-1700, regardless of when they last slept. These are particularly good times to take advantage of this naturally occurring sleep tendency by napping. Even a 2-hr nap can make a measurable difference in performance that occurs 6-14 hr later.

Social interaction. During the period of 20-44 hr without sleep, environmental stimulation can play a significant role in minimizing performance degradation. Beyond this period of wakefulness its effect is greatly limited, although it is still more effective than no stimulation, especially at night. In this context, stimulation refers to physical activity and postural changes, meaningful conversation, and other significant social interaction. Work environments that include solitary work, sedentary posture, and/or passive monitoring components are the most vulnerable to performance degradation. This would include planners and others that are toward the high end in the chain of command. Alerts, incentives, and other transitory events may provide some temporary improvement in performance but this “bounce” likely will not be sustainable beyond about 2 hr.

Physical activity. The earliest studies of sleep deprivation involved forced physical activity to keep subjects awake. While the motivation and desire to remain physically active greatly diminishes with sleep loss, actual physical strength and physical performance are very resistant to degradation. Therefore, having the harshest sleep/wake schedules for people with the greatest physical activity demands is a reasonable strategy and better than the reverse. In the aircraft carrier environment, this means those doing the heavier physical work may better tolerate the sleep deprivation than those who are desk-bound, although they will still need physical rest breaks to allow for muscle recovery. Whereas errors and lapses in desk-type work could certainly compromise mission success in many ways, mistakes by those performing the physical labor will probably carry a higher risk of personal physical injury, mechanical systems failure, and safety violations.

Organizational factors. Certain organizational factors can act to minimize the effects of sleep loss. These include high degrees of discipline and job knowledge, factors likely to be found in most military environments. In addition, an awareness and acknowledgment that uncontrolled sleep episodes can and will occur (as opposed to a denial of this fact) can also help put personnel on alert to this vulnerability.

Diet. While there is no consensus that diet can reduce the effects of sleep deprivation, per se, there is some evidence that boosting the levels of the amino acid tyrosine may help the body in withstanding the effects of stress. Neurons using catecholamine neurotransmitters increase their firing rate under stressful conditions. Animal studies have shown that making more tyrosine available can allow an increase in catecholamine synthesis, thereby reducing the negative behavioral effects of stress. A recent Navy study using human subjects demonstrated that, during a single night without sleep, tyrosine administration (150 mg/kg) was associated with a significant amelioration of the usual performance decline seen on a psychomotor task and a vigilance task. The dosing corresponds to about 12 g of tyrosine for a 175 lb person. Unfortunately, tyrosine is not found in foods in such large amounts and there are no data that directly address the question of whether beneficial behavioral effects are associated with lower levels of dietary tyrosine. Tyrosine is also available in health food stores where it is sold as a dietary supplement but, as such, it is not produced under FDA control and so one can not be completely assured of its purity, etc. There would probably be little harm in loading up on

tyrosine-rich foods such as wheat germ, granola, oats, cheeses, dairy products, chocolate, yogurt, pork, turkey, chicken, and wild game. Whatever the specific foods ingested, long periods of continuous wakefulness and eating during the late night/early morning hours can be expected to result in increased numbers of gastrointestinal complaints as occur frequently with shift workers.

Would stimulants be helpful?

Stimulants, when used appropriately and under close physician control, can help alleviate some of the effects of sleep loss.

A thorough discussion of stimulant use is beyond the scope of this document and more detailed scientific information can be found in several of the papers listed in Appendix C. There is ample evidence that amphetamines, in particular, are effective in ameliorating the effects of sleep loss, although newer and safer compounds are currently being developed. It is understood that amphetamine use is currently prohibited in the Navy. Should that prohibition be lifted, recommendations for inclusion in any plan for amphetamine use are:

- Pre-screen all who might be administered a stimulant during an actual operation
- Develop a written policy covering (at least):
 - procedure for approval of stimulant use in a given squadron or group
 - the nature of the medical oversight
 - criteria for initiating and discontinuing use
 - dosing schedule (including consideration of the effects on sleep initiation)
 - tracking of actual usage
 - collection of feedback on side effects and effectiveness
 - control of access and administration

Amphetamines. Of the various alternatives, Dexedrine (dextroamphetamine) may be the most readily available to the Navy physician. It is also one of the more heavily-investigated stimulants in laboratory sleep deprivation studies. The U.S. Army has tested Dexedrine in a laboratory study after 48-hr of sleep deprivation using doses of 5, 10, and 20 mg. There were dose-related increases in the time to fall asleep, with variable effects on the performance tasks and subjective measures. Interestingly, despite concerns of undesirable changes in decision making behavior with amphetamine use, with the 20-mg dose there appeared to be a change from the more liberal approach to decision making that occurs with increasing sleep loss, back to the more typical conservative approach. Cardiovascular side effects are not unexpected at the higher doses and were reported for one subject. It should be emphasized that the authors of this study caution about the generalizability of the results to the field situation which can differ in many important ways from the laboratory.

Dexedrine was used by the U.S. Air Force during Desert Storm with apparent success and no reported side effects. One study reported that 96% of the 192 aviators responding to a survey that they used amphetamines during actual combat considered their use to be “beneficial or

essential to operations.” Dosing was 5 mg every 4 hr. It should be remembered however, that these were self-report data, with no objective performance measures.

Any protocol for actual amphetamine use will need to consider many factors. The following suggestions are submitted for consideration in any plan for Dexedrine use. First, it should be employed strategically, rather than routinely, as with caffeine (see above). Consideration should be given to timing the first dose in a series to the late night/early morning hours (0100-0300). When given orally, there is about a 45-60 min delay in onset of the stimulant effect of Dexedrine and maximal blood levels occur after 6-8 hr. Consideration might be given to a dosing plan of 5-10 mg every 2-3 hours during the nighttime hours with a limit of 2-3 consecutive doses. (However, it should be noted that Dexedrine is more likely than caffeine to interfere with sleep should a sleep opportunity become available.) Dosing might not be initiated until the third night of the four-day SURGEOP and stopped at the end of the second consecutive night of use. Caffeine might be used during the daytime in lieu of amphetamine. Naturally, any decisions on actual usage, dose, and timing should only be made after careful consideration of both the relevant literature and the many operational factors.

Should sleep be possible, how might work schedules be arranged to minimize the impact of changing shifts and reduced sleep opportunities?

When possible:

- *Nap during the midafternoon (1400-1700) or nighttime/early morning hours (0200-0800)*
- *Minimize exposure of night work to circadian trough (~0300-0500)*
- *Minimize unusually early rise times and keep report times constant (or shift them later, not earlier) on successive days*
- *Minimize wake durations longer than 16-20 hr*
- *Provide sufficient time between shifts for a reasonable sleep opportunity*
- *Rotate shifts in a clockwise direction (day, evening, night)*

The importance of napping was discussed previously. Scheduling naps during the midafternoon (1400-1700) or nighttime/early morning hours (0200-0800) will take advantage of the natural sleep tendency that occurs at those times of day due to the circadian rhythm of sleepiness/alertness. This will translate to reduced sleep latency and more efficient sleep.

When possible, it is highly desirable to minimize the exposure of night work to the time of the daily circadian trough in alertness/performance (about 0300 - 0500). When it is not possible, it is important to realize that crew operating during this time period are highly vulnerable to errors and accidents due to the strong signal for sleep from the circadian clock. This is a time when countermeasures should be used and additional oversight provided, and the awareness of the crew raised regarding the increased risk.

Minimizing very early report times will also help avoid the requirement of performing during this circadian low period of 0300 - 0500. Early report times are also a significant problem

because of the need to go to bed earlier than usual in order to obtain the same amount of sleep. Attempting to sleep at an earlier time means dealing with the “wake maintenance zone,” the 2-3 hr period prior to the usual sleep time when the circadian pacemaker actually is sending its strongest signal for wakefulness. Frequently this means that “going to bed” a couple of hours early does not translate to going to sleep much earlier at all.

Keeping the wake duration less than 16-20 hr will minimize the drop in alertness and performance even among those most sensitive to lost sleep. As described previously, it is between 20 and 44 hr of wakefulness that a majority of people show at least a moderate level of performance impairment.

Sufficient opportunities for sleep between shifts will avoid the accumulation of a sleep debt. A break between shifts that includes a “sufficient opportunity” for sleep should be long enough for 8 hours of sleep, a meal, and a shower. When night work is necessary, schedule sleep as closely as possible to the end of the night shift to take advantage of any remaining opportunity to sleep before the day proceeds very far. Day sleep will be shortened and inefficient because of the rise in body temperature in the morning hours and the “wake-up” signal coming from the circadian pacemaker.

When shifts rotate, using a clockwise rotation (day, evening, night) takes advantage of the natural tendency to stay up later and get up later than the preceding day. Rotating in the opposite, counter-clockwise direction (day, night, evening), requires going to bed earlier and getting up earlier with each shift change -- a more difficult process. For similar reasons, keeping report times constant or shifting them to later times on successive days also takes advantage of the natural tendencies of the circadian pacemaker and reduces the likelihood of sleep loss and its associated effects.

What kinds of information can be gathered with minimal impact to determine the effects of this SURGEOP and serve as a comparison for future exercises?

Other stress-related responses to SURGEOPS might include increases in the use rate of certain shipboard facilities and services. A brief, 5-min survey could also be used to unobtrusively provide self-report information on the extent and severity of the problems experienced.

Information on the impact of SURGEOPS on performance, mood, and other behavior is critical. Several already-available measures that may reflect the fatigue and stress responses expected from the crew include injuries, incidents and accidents, and legal/disciplinary measures. The use rate for these services can be monitored and compared with other time periods. In addition to this type of information it could be very informative to conduct a brief survey of those groups of individuals expected to be at high risk for sleep-loss-related problems. General guidelines for such a survey are provided in Appendix B.

Are there any criteria for readily determining whether a SURGEOP was conducted safely?

It is very difficult to measure whether a given operation was conducted “safely” or not. Given that aircraft and other accidents are relatively rare occurrences, their absence does not necessarily signify a safe operation. Consequently, they should not be relied upon as the sole outcome measure.

A single, successful, accident-free exercise, does not speak to the true underlying probability of occurrence of a serious incident or accident. Fortunately, the probability of an accident is still likely to be low enough that no conclusions can be drawn from one accident-free exercise. On the other hand, an imperfect safety record does not mean that measures taken did not still appreciably reduce the risk exposure. Only repeated experience with similar exercises, and the collection of information described above (as well as incidents and accidents) can begin to expose the true underlying risks involved. In the meantime, all practical preventive measures can help reduce the vulnerability for decrements in alertness and performance that in turn reduce the safety margin.

APPENDIX A: COUNTERMEASURE SUMMARY

Caffeine

- Gradually reduce caffeine use and stabilize at 50% usual amount for at least 2 days (preferably a week) before SURGEOP
- Avoid caffeine until 18-20 hr into first day of SURGEOP
- Use caffeine *strategically*:
 - Start caffeine use at 0100-0300 and taper by 0800
 - Use caffeine in midafternoon to counter sleepiness
 - Avoid caffeine after awakening, during alert periods, and within several hr of sleep
 - Start caffeine use 30 min before the desired effect (which lasts for 3-4 hr)

Naps

- Recognize that sleep is a response to a basic physiological need (like that for food and water) and satisfy that need by obtaining sleep wherever and whenever possible
- Use the approach that some sleep is always better than none
- Use sleep opportunities for sleep, not just rest, as rest is *not* a substitute for sleep
- To avoid sleep inertia, limit nap to ≤ 45 min or extend nap to about 2 hr
- Schedule a nap just *before* an extended wake period or early into it
- Ideal nap times are from 0200-0800 and 1400-1700 during a SURGEOP

Environmental Stimulation/Physical Activity

- Environmental stimulation can reduce some effects of sleep loss, especially during first 20-44 hr. Forms of stimulation: meaningful conversation and social interaction, changes in posture, changes in tasks
- Minimize solitary work, sedentary posture, and passive monitoring tasks
- Minimize monotony and boredom by introducing incentives and other transitory events
- Avoid scheduling critical tasks at times of greatest vulnerability to lapses, errors, and other performance decrements (0300-0500)
- Maintain a high physical fitness level
- Physical activity can be used to ward off sleep provided breaks are allowed for muscle recovery

Other Strategies Before and During SURGEOPS

- Maintain high levels of discipline and organizational structure
- Minimize exposure of nightwork to circadian trough (0300-0500)
- Minimize unusually early rise times
- Keep report times constant or shift later, not earlier, on successive days
- Minimize wake durations longer than 16-20 hr
- Provide sufficient time between shifts for reasonable sleep opportunity in addition to meals, shower, etc.
- Rotate shifts in clockwise direction (day, evening, night)

APPENDIX B: SURVEY GUIDELINES

In structuring a brief survey to collect information during a SURGEOP, the following guidelines are provided based on past experience.

Subject selection & sampling:

- Use either all those who volunteer or a random selection from a group of volunteers
- Insure confidentiality
- Code all data carefully for time & day and sample frequently throughout 4-day SURGEOP
- Collect data for the 12- or 24-hr period before or after 96-hr SURGEOP, for comparison with SURGEOP data. Sample first question: How much sleep was obtained in the last three days?

Scale construction:

- Better to construct one's own tailored scale than to use standard "sleepiness" scales
- In constructing a scale, be as specific as possible in the type of information asked
- Use even-numbered scales to force responses away from the exact middle
- Specific scale-construction suggestions:
 - A. To assess sleep, at a minimum ask (for the specified time period):
 - How much sleep did you get?
 - Where did you sleep (in bunk or in work area)?
 - B. To assess performance in the last hour, shift, or specified work period, include:
 1. A simple checklist on performance, e.g.:
 - Doing well
 - Doing okay
 - Doing less well than I had hoped (more mistakes than I had liked)
 2. Questions such as:
 - What were you doing?
 - How much, if any, has your amount of sleep affected your performance?
 - What kinds of performance changes, if any, did you experience?
 - How well did you do your job?
 - Did you make a big mistake? If so, what?
 - Did you nod off? If so, for how long?
 - How is your sleep situation affecting your morale?
 - How much is the work schedule affecting the abilities of the person you are working closest with?
 - How well do you expect to do your job in the next hour, shift, or specified work period?
 3. Visual analog scales, such as:
 - alert/sleepy; well rested/exhausted; sick/healthy; motivated/unmotivated(Also include scales that shouldn't change with sleep loss, e.g., happy/sad)
 4. Questions on countermeasures, such as:
 - Did you use any coffee? If so, how much?
 - Did you do anything else to keep awake? If so, what?
 - List and rate the effectiveness of any countermeasures used

APPENDIX C: SELECTED ADDITIONAL SOURCES

Education & Training

Rosekind, M. R., Gander, P. H., Connell, L. J., & Co, E. L. (in press). *Crew factors in flight operations X: alertness management in flight operations*. NASA Technical Memorandum. Moffett Field, CA: Ames Research Center.

Sleep Deprivation & Performance

- Bonnet, M. H. (1994). Sleep deprivation. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine* (2nd ed.). (pp.50-67). Philadelphia: Saunders.
- Dinges, D. F. (1995). Performance effects of fatigue. In *Fatigue Symposium Proceedings* (Nov 1-2, 1995). (pp. 41-46). Washington, DC: National Transportation Safety Board.
- Dinges, D. F. (1992). Probing the limits of functional capability: the effects of sleep loss on short-duration tasks. In R. J. Broughton & R. D. Ogilvie (Eds.), *Sleep, arousal, and performance*. (pp. 176-188). Boston: Birkhauser.
- Dinges, D. F., & Chugh, D. K. (1997). Physiological correlates of sleep deprivation. In J. M. Kinney and H. N. Tucker (Eds.), *Physiology, Stress and Malnutrition: Functional Correlates, Nutritional Interventions*. New York: Lippincott-Raven.
- Dinges, D. F., & Kribbs, N. B. (1991). Performing while sleepy: effects of experimentally-induced sleepiness. In T. H. Monk (Ed.), *Sleep, sleepiness and performance*. (pp.97-128). Chichester: Wiley.
- Horne, J. A. (1991). Dimensions to sleepiness. In T. H. Monk (Ed.), *Sleep, Sleepiness and Performance*. (pp. 169-196). Chichester: Wiley.
- Kribbs, N. B., & Dinges, D. F. (1994). Vigilance decrement and sleepiness. In J. R. Harsh & R. D. Ogilvie (Eds.), *Sleep onset mechanisms*. (pp. 113-125). Washington, DC: American Psychological Association.

Partial Sleep Deprivation

- Carskadon, M. A., & Roth, T. (1991). Sleep restriction. In T. H. Monk (Ed.), *Sleep, Sleepiness and Performance*. (pp. 155-167). Chichester: Wiley.
- Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., Aptowicz, C., & Pack, A. I. (in press). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep*.

Countermeasures to Sleep Deprivation

- Bonnet, M. H., Gomez, S., Wirth, O., & Arand, D. L. (1995). The use of caffeine versus prophylactic naps in sustained performance. *Sleep* 18(2), 97-104.
- Caldwell, J. A., Caldwell, J. L., Crowley, J. S., & Jones, H. D. (1995). Sustaining helicopter pilot performance with Dexedrine during periods of sleep deprivation. *Aviation, Space, and Environmental Medicine*, 66(10), 930-937.
- Dinges, D. F. (1996). Napping strategies. In *Fatigue Symposium Proceedings* (Nov 1-2, 1995). (pp. 41-46). Washington, DC: National Transportation Safety Board.
- Emonson, D. L., & Vanderbeek, R. D. (1995). The use of amphetamines in U.S. Air Force tactical operations during Desert Shield and Storm. *Aviation, Space, and Environmental Medicine*, 66(3), 260-263.
- Krueger, G. P. & Babkoff, H. (Eds.). (1992). Stimulants to Ameliorate Sleep Loss During Sustained Operations. *Military Psychology*, 4(4). (Special issue devoted to use of stimulants in SUSOPS.)
- Neri, D. F., Wiegmann, D., Stanny, R. R., Shappell, S. A., McCardie, A., & McKay, D. L. (1995). The effects of tyrosine on cognitive performance during extended wakefulness. *Aviation, Space, and Environmental Medicine*, 66(4), 313-319.
- Owasoyo, J. O., Neri, D. F., & Lamberth, J. G. (1992). Tyrosine and its potential use as a countermeasure to performance decrement in military sustained operations. *Aviation, Space, and Environmental Medicine*, 63, 364-369.
- Penetar, D., McCann, U., Thorne, D., Kaminori, G., Galinski, C., Sing, H., Thomas, M., & Belenky, G. (1993). Caffeine reversal of sleep deprivation effects on alertness and mood. *Psychopharmacology*, 112, 359-365.
- Rosekind, M. R., Graeber, R. C., Dinges, D. F., Connell, L. J., Rountree, M. S., Spinweber, C. L., & Gillen, K. A. (1994). *Crew factors in flight operations IX: effects of planned cockpit rest on crew performance and alertness in long-haul operations*. NASA Technical Memorandum. Moffett Field, CA: Ames Research Center.